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RESEARCH PAPER

Structure changes and succession dynamic of the natural secondary forest after severe fire interference

LIU Bin-fan[1,2], LIU Guang-ju[2*] , WANG Zhi-cheng[3]

[1]*College of Forestry, Northeast Forestry University, Harbin 150040, P. R. China*
[2]*Heilongjiang Forest Engineering and Environment Research Institute, Harbin 150081, P.R. China*
[3]*Heilongjiang Forest Fire Prevention Office, Harbin 150090, P.R. China*

Abstract: The structure and dynamic succession law of natural secondary forest after severe fire interference in recent 20 years were studied by adopting the method of deducing time series from the spatial sequence of vegetation in Heihe region, Heilongjiang, China. Two typical and widely distributed forest types in the study area, namely forest type A and forest type B, were selected as study subjects. Forest type A is pure broadleaf forest or broadleaf mixed forest mainly composing of superior *Betula platyphylla* and *Populus davidiana* in the area with gradient <25°, while forest type B is pure forest or mixed forest composing of superior *Quercus mongolica* and *Betula davurica* in the area with gradient >25°. Species richness, vegetation coverage, important value, and similarity index of community in different layers (Herb, shrub, small tree, and arbor layers) were investigated and analyzed for the two typical forests. The results show that after fire interference, the species richness and coverage in each layer in forest type A were higher than that in forest type B. Both for forest type A and B, with elapse of post-fire years, the species richness and coverage of herbs and shrubs showed a decline tendency, while those of arbor layer present a rising tendency. Through comparison of the important values of species in each layer and analysis of community structure changes, the dynamic process of post-fire vegetation succession for forest type A and B was separately determined. Post-fire 80 years' succession tendency of forest type A is *B. platyphylla* and *Larix gmelinii* mixed forest. Its shrub layer is mainly composed of *Corylus heterophylla* and *Vaccinium uliginosum*, and herb layer is dominated by *Carex tristachya*, *Athyrium multidentatum*, and *Pyrola incarnate;* whereas, the post-fire 80 years' succession of forest type B is *Q. mongolica* and *B. davurica* mixed forest. Its shrub layer is mainly composed of *lespedeza bicolar* and *corylus heterophylla* and herb layer is dominated by *Carex tristachya, Asparagus densiflorus,* and *Hemerocallis minor*.

Key words: natural secondary forest; vegetation succession; fire interference; burned areas; species richness; important value; similarity index; succession law.

Introduction

At present, 80% of terrestrial ecosystems are subject to artificial and natural interferences, so interference study becomes an active area of the current ecology (Zhu and Liu 2004). Natural interference plays a vital role in maintaining species diversity, community stability, and nonhomogeneity of landscape of forest ecosystem (Schroeder and Ajith 2002), and it is even viewed as one of maintaining mechanisms of species population, which serves as a driving force of community succession (Attiwill 1994; Shugart and West 1980; White 1979; Xu et al. 1997). A great number of studies have been conducted on succession and restoration of burned blank and related factors. Those studies mainly including: forest fire and its effect on surrounding environment (Grogan etal 2000; Lloret et al. 2002; Romme 1982), dynamic changes of species population in burned blank (Borchert et al. 2003；Hanes and Jones 1967; Preston and Baldwin 1999; Shafi and Yarranton 1973), effects of forest fire factors, e.g. fire intensity, fire frequency, and fire size, on vegetation succession (Gill 1975; Keeley et al. 1981; Phillips and Shure 1990), influences of geographic position, terrain, as well as climate on vegetation succession (Cwynar 1987; Turner 2003), succession phase and process after fire (Fastie 1995). In addition, in recent years, the simulation model of post-fire vegetation succession in large space-time scale has been established, which can be used to predict long-term dynamic variation of forest after fire (He and Mladenoff 1999; Kercher and Axelrod 1984). After the big fire occurred on May 6th 1987 in Daxing'an Mountains, China, a few studies on post-fire vegetation succession, fire cause, and fire

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Biography: LIU Bin-fan (1964-), male, Ph.D. candidate, researcher in Heilongjiang Forest Engineering and Environment Research Institute, Harbin 150081, China; major in the interference ecology. E-mail:liubinfan88@163.com
*Corresponding author: LIU Guang-ju, liuguangju1967@163.com
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losses were carried out (Luo 1987; Shu et al. 1996; Wang et al 2004; Wang et al. 2006 a; Wang et al. 2006 b; Yang and Li 1992). However, most of these studies were qualitative analysis due to lack of long-term positional observation data, focusing mainly on dynamic of dominant tree species but less on effect of ground-layer (shrub and herb) on trees. Moreover, the studies related to vegetation succession only discussed the general way of succession; whereas few studies focused on succession mechanisms of vegetation. Meanwhile, no available information was given on difference in species of various layers in succession process, as well as the cause of the difference.

In the present study, we analyzed the succession process and the community structure of natural secondary forest a 20-year heavy burned area in Heihe Region of Heilongjiang Province, China using the method of deducing time series from spatial sequence of vegetation. The objective of this study was to predict the long term dynamic variation of forest vegetation after fire, so as to provide data and theory for fire prevention and fire use.

Study area

The study was conducted in Nenjiang County and Aihui District (48°42′− 58°51′N, 124°45′−127°119′E) of Heilongjiang Province, China. The study area is located at the northern end in cool temperature zone. Trees in this area have over six months of dormancy. Zonal soil is dark brown soil. Annual precipitation is in range of 450−500 mm, mainly concentrating in July to August. Occurrence of forest fire is highly possible in spring and autumn. Forest vegetation is dominated by natural secondary forest in the area. Climax community of pristine zone is the bright coniferous forest dominated by *Larix gmelini*. Years of cutting and forest fire resulted in a converse succession of forest community. Now, the current forest cover is the natural secondary forest dominated by white birch (*Betula platyphylla*), Mongolian oak (*Quercus mongolica*) and black birch (*Betula davurica*), and the artificial larch forest. Understory species include mainly *Curylus heterophylla*, *Lespedeza bicolar*, and *Rhododendron dauricum*), with a coverage of about 10%. Groundcover is mainly composed of *Canex schmidtii*, *Canex ussuiensis*, *Deyeuxia angustifolia*, *Athyrium multidentatum*, with coverage of around 70%.

Study method

Setting sample plot and investigation

Sample plots were set in the natural secondary forest formed by long-term fire interference not man-made interference in recent 20 years, where the arborous layer was severely damaged, *B. platyphylla, Q. mongolica*, *B. davurica* and *P. davidiana* with strong sprouting ability become pioneer species of regeneration, and the distribution of tree species at different gradients has an evident difference. We selected two typical forest types as study subjects; that is, (1) forest type A, pure broadleaf forest or broadleaf mixed forest mainly composing of superior *B. platyphylla* and *P. davidiana* in the area with gradient <25°; (2) forest type B, pure forest or mixed forest composing of superior *Q. mongolica* and *B. davurica* in the area with gradient >25°. The location of sample plots are shown in Fig. 1.

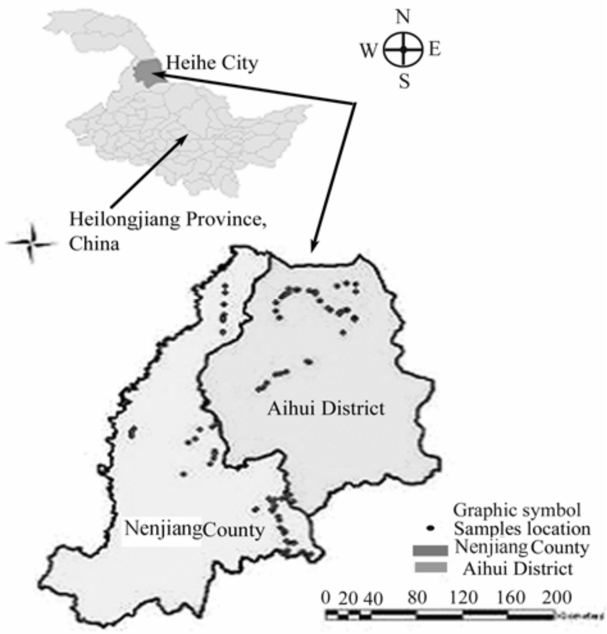


Fig. 1 Distribution of investigation plot

In total 133 sample plots were set up, from which we selected 36 sample plots (with a size of 30 m×30 m for each) to conduct investigation. Each three plots were set for 1-year, 4-year, 9-year, 15-year, and 20-year burned areas in forest type A and for 1-year, 4-year, 7-year, 13-year, and 20-year in forest type B at upper slope; at meantime, also each three plot were set for unburned area (80-year-old forest) in both forest types. Vegetation investigation was carried out in burned areas and unburned areas in 2006. The species, tree number, and diameter of arbor trees (diameter at breast height (DBH) >2 cm) were recorded in each plot. In each sample plot, 4−5 quadrats of 5m×5m was set to investigate the species, quantity and height of shrub and sapling tree (DBH ≤2cm), and 4−5 1-m×1-m quadrats were set to investigate the species and quantity of herbs and grass. The coverage of arbor, small tree (sapling), shrub, and herb layer were also estimated during investigation (arborous layer uses shade density).

GPS technology was adopted to determine co-ordinate of sample plot. The environmental condition, stand type, elevation, gradient, slope aspect, canopy structure, blackened height of tree fuel loading and coarse woody debris (including dead standing trees and fallen trees) were all recorded. In field investigation, we cut a cant at one side of the fire scar to determine burn year by checking the annual rings from cambium to xylanthrax layer; meanwhile, one typical fire scar tree was selected in each plot for lab analysis of age structure.

Reconstruction of fire interference history of sample plot

We used the available proof and data of fire interference to analyze and judges times of fire occurrence, occurred year and burn-

ing degree of the burned blank to rebuild the history of fire interference of sample plot (Liu et al. 2008). According to the investigation data of sample plots and fire scar analysis, we analyzed forest age-class structure, pre-fire remaining quantity of trees, pre-fire tree age peak, post-fire regeneration, as well as the vegetation characteristics such quantity and coverage of arbor, shrub and herbs. Finally, the fire occurrence times, fire occurrence year, and burn intensity of the burned area in recent 20 years were determined in light of tree with fire scar, coarse woody debris, fuel accumulation, blackened height, quantity of the blackened trees, and state of dead and alive fuels. The burn intensity was divided into three levels based on volume proportion of death trees by burn: heavy burn (≥60%), moderate burn (31%−60%) and light burn (≤30%).

Community structure

Species richness was investigated according to species number in the sample plot. Vegetation coverage of arbor layer, sapling layer, shrub layer, and herb layer was separately estimated in this study (shade density is used for arborous layer). Important value (IV) is an comprehensive index to represent the position and role of a certain species in community (Cao et al. 2000; Guo et al. 2004; Zhang et al. 2005). To obtain post-fire vegetation succession sequence under the condition without artificial interference, we calculated the important value (IV) for each species in the burned blanks with different burn years. The following two equations were used to calculate the important values of each arbor species (Equation 1) and sapling, shrub and herb species (Equation 2).

$$IV = R_D + R_F + R_D \tag{1}$$

$$IV = R_D + R_F + R_C \tag{2}$$

where, IV is the important value of species, R_F is the relative frequency of species, and R_D is the relative dominance of species, and R_C is the relative coverage.

For similarity: Sorensen similarity index was adopted to calculate the similarity of community in different developmental stages (Zhang et al. 2003; Zhang et al. 2004):

$$C = Z_j /(a+b) \tag{3}$$

where, C is the similarity of community, Zj is the sum of important values of common species in the two communities, and a, b separately means the sum of important value of all species in two communities.

Succession process of community

The sample plots for different forest types and heavy burned areas were screened. With the method of deducing time series from the spatial sequence of vegetation, we deduced the basic succession process of different types of natural secondary forest within 20 years after heavy fire interference through comparing the important values of arbor, shrub and herb species of heavy burned area.

Data processing

Cross section analysis, regression analysis and correlativity test were conducted by using SPSS13.0 statistical software.

Result and analysis

Structural features of natural secondary forest after heavy fire interference

Species richness

After heavy fire interference, the species richness of the herb, shrub, arbor, and all species in forest type A presents a power function relation with post-fire years (Fig. 2), with a actual significant level of p=0.001, 0.039, 0.001, and 0.000, respectively, and all reached significant level ($p<0.05$) or even most significant level ($p<0.001$). With the increase of post-fire years, the species richness of herb, shrub, and all species show a decrease tendency, but that of the arbor species presents an increase trend; whereas the richness of all species shows a positive correlation with the variation in species richness of herbs and shrubs.

Species richness of herb, shrub, arbor and all species in forest type B separately shows a logarithmic function, exponential function, power function, and power function relations with post-fire years (Fig. 2), with a actual significant level of P=0.014, 0.026, 0.030, and 0.034, respectively, all reaching significant correlation($p<0.05$). The change trend of species richness of forest type B is similar to that of forest Type A, but its species number in different layers is significantly lower than that of forest type A.

Coverage

The coverage of herb, shrub, sapling tree and arbor tree of forest type A separately presents a logarithmic function, exponential function, logarithmic function, and power function relations with post-fire years (Fig. 3), with a actual significant level of p=0.006, 0.000, 0.048, and 0.014, and the correlation degree all reached significant level ($p < 0.05$) and even most significant level (p<0.001). With the increase of post-fire years, the coverage of herb, shrub, and sapling tree presents a decrease trend, but that of arbor shows an increase trend and finally reaches a relatively stable level. The total coverage of species has no obvious relation with post-fire year span. Within one to four years after forest fire, the coverage of herb and shrub are obviously higher than that of arbor due to the fact that drought-resistance and light-preference plants intrude quickly. As post-fire years elapse, coverage of arbor increases gradually, exceeds that of herb and shrub, and goes to crown closure gradually.

Coverage of herb and arbor of forest type B separately presents an exponential function and power function with post-fire years (Fig. 3), with an actual significant level of p=0.035 and p= 0.004, respectively, all reaching significant correlation ($p<0.05$); whereas, the coverage of shrub and sapling tree has no significant correlation with post-fire years ($p>0.1$). As post-fire years elapse, herb coverage shows a decrease trend, while the coverage

of tree presents an increase tendency. The coverage of each layer in forest type B is obviously lower than that in forest type A. Degenerated grass and shrub-grass occurred on the sunny ridge slope after fire.

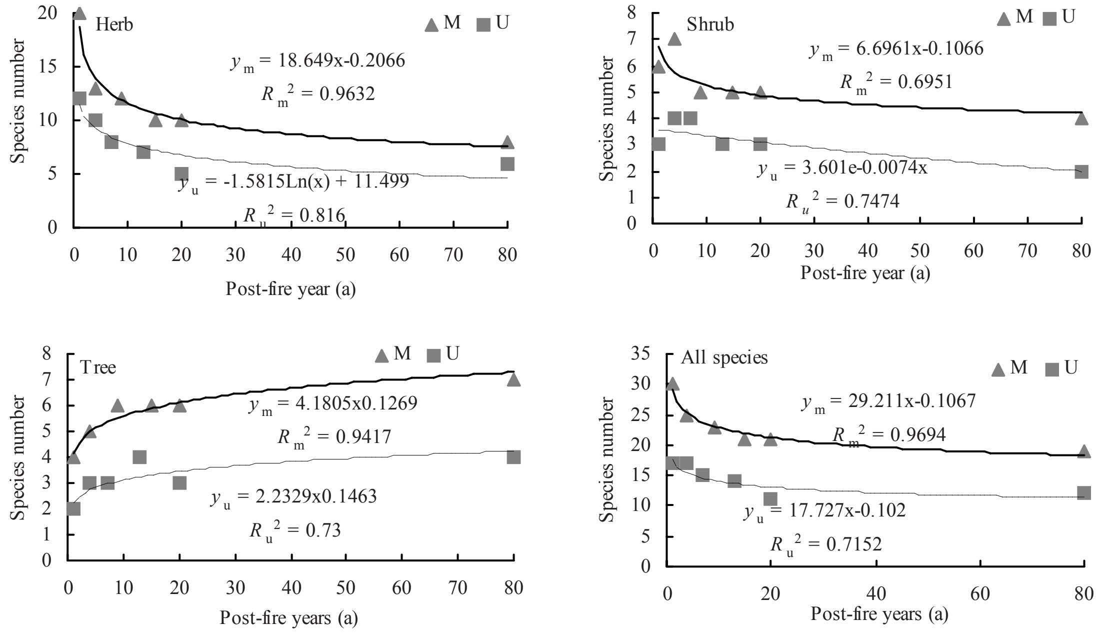
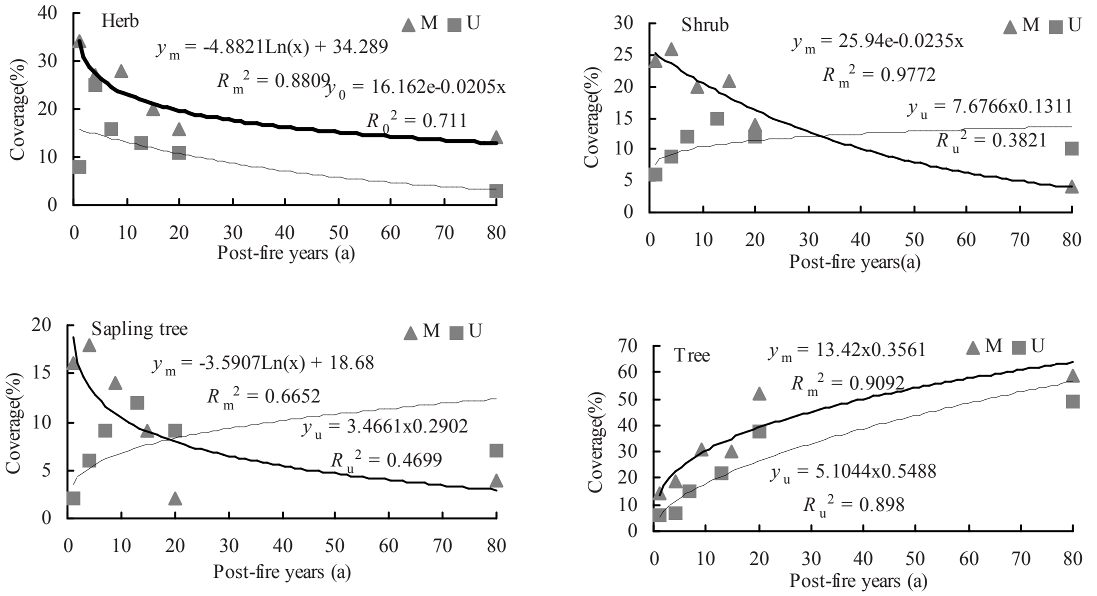


Fig.. 2 Specie richness of herb, shrub, sapling and tree layers in different post-fire years in the heavy burned area

Notes: M--- Forest type A; U--- Forest type B



Notes: M--- Forest type A; U--- Forest type B

Fig. 3 Vegetation coverage of herb, shrub, sapling and tree layers in different post-fire years in the heavy burned area

Important value

Forest type A: Important values of species in each layer of forest type A are listed in Table 1. After heavy burning in 2006, at the early stage of succession, the original vegetation were damaged and light and heat conditions were changed, which providing a feasible habitat for herb and shrub growth. Some herbs and shrubs of light preference and nitrogen fixation, with strong adaptability, such as *Canex ussuiensis*, *Deyeaxia angustifolia*, *Canex schmidtii*, *Vicia cracca*, *Filipendula palmate*, *Chamaenerion angustifolium*, *Artemisia* spp., *Lespedeza bicolar*, *Corylus* spp., *Rhododendron dauricum*, *Sorbaria sorbifolia*, *Lonicera edulis*, and *Spiraea salicifolia*, etc., first grow in the burned blank. The species numbers of herb and shrub increase, and the total coverage of herb-shrub layer may reach 90%. Along

with the increase of vegetation coverage, the regenerated sapling and trees cover the burned area, and shade groundcover begin to grows, e.g. *Athyrium multidentatum*, *Equisetum sylvaticum*, *Pyrola incarnate*, *Rosa davurica*, *Vaccinium uliginosum*. However, the species with strong adaptability, such as *C. ussuiensis*, *C. schmidtii*, *D. angustifolia*, *Corylus hetrophylla*, and *L. bicolar,* have an important position in the groundcover through the whole succession process from plant intrusion to stable phase.

Species number of arbor in this area is less and has no big change. Upper layer trees were sparse in the burned area in 2006, mainly composing of seedlings of *B. platyphylla*, *Salix matsudana*, *P. davidiana*, *B. davurica*. *Salix* spp. and *P. davidiana* have strong reproducing ability, but hard to occupy dominance due to the relatively weak fire resistance and adaptability. *B. platyphylla* has seed propagation and sprouting ability. At the early stage of post- fire succession, *B. platyphylla* seedlings in the burned area cluster through initiation and occupy the burned area quickly. After 4−9 years *B. platyphylla* becomes dominant tree species of the arborous layer. Arborous layer mainly composing of *B. platyphylla* gradually formed in the burned area of post-fire 15 years, with a high coverage, and mixed with a certain numbers of *Larix gmeini*. *L. gmeini* generates by seed propagation and is shade tolerant. Heavy fire interference may lead to a converse succession from larch forest to birch forest, so that the *L. gmeini* cannot become a constructive species in a short period. However, in the sample plot with *L. gmeini* provenance in the study area, it was found that *L. gmeini* can regenerate naturally and form a renewal layer; at meantime, it can form a broad-leaf-conifer mixed forest with *L. gmeini* as constructive species under the condition without heavy interference.

Forest type B: Important values of species in each layer of forest type B are listed in Table 2. After heavy burn, the soil of forest type B is dry and poor in water conservation. In the early stage of succession, the first intruded species include *Canex tristachya*, *Hemerocallis minor*, *D. angustifolia*, *E. sylvaticum*, *Vicia* spp., *L. bicolor*, *C. heterophylla*, *R. davaria*, *R. dauricum*, and *Sorbaria sorbifolia*. These are light preference, drought resistance and barrenness tolerance species with strong adaptability. Along with the increase of vegetation coverage on burned site, the saplings of *Q. mongolica* and *B. davurica,* with characteristics of cold resistance, drought resistance and strong sprouting ability, occupy the burned site gradually. However, on ridge section of forest type A, the vegetation restoration is rather slow after heavy fire interference, and the species richness and vegetation coverage of each layer are obviously lower than that of forest type A. Even if the *Q. mongolica* forest that has strong adaptability and is regarded as fire climax can forms, the trees grow slowly due to poor site and climatic conditions, and the top-shoots are easily frozen to death in winter, forming short and bent trees. Such *Q. mongolica* forest only plays a role in erosion protection of anticorrosion slope. After fire, some forests, especially *Q. mongolica* forest, are easily infected with disease and pest and likely to suffer fire again, thus resulting in a vicious circle and even degenerating to steppe community. As a result, there is no forest in part steep land in Heihe Region, even making reforestation very difficult.

Table1. Important value of species in different stages after forest fire in forest type A (middle and down slope)

Layer	Species	Important value (%)					
		S_1	S_4	S_9	S_{15}	S_{20}	S_{80}
A	*Canex ussuiensis*	66.19	75.16	39.02	69.42	60.20	84.12
	Deyeuxia angustifolia	60.59	99.93	58.05	32.14	0.00	0.00
	Vicia cracca	28.30	12.10	0.00	0.00	0.00	0.00
	Filipendula palmata	18.55	13.93	18.08	13.86	35.40	25.82
	Canex schmidtii	17.72	39.40	82.99	98.04	84.60	93.65
	Chamaenerion angustifolium	16.70	0.00	4.33	2.37	0.00	0.00
	Hemerocallis minor	15.26	14.31	0.00	0.00	0.00	5.77
	Artemisia laciniata	12.08	0.00	0.00	0.00	0.00	0.00
	Fragaria orientalis	10.77	0.00	0.00	0.00	0.00	0.00
	Sanguisorba parviflora	10.73	0.00	0.00	0.00	0.00	0.00
	Pteridium aquilinum	8.16	0.00	0.00	0.00	0.00	0.00
	Sanguisorba officinalis	6.08	0.00	0.00	0.00	0.00	0.00
	Arctium lappa	5.79	0.00	0.00	0.00	0.00	0.00
	Saussurea amurensis	5.17	0.00	0.00	0.00	0.00	0.00
	Cacalia hastata	5.08	3.96	4.25	0.00	0.00	0.00
	Geranium sibiricum	5.03	0.00	0.00	0.00	0.00	0.00
	Deyeuxia langsdorffii	2.85	0.00	0.00	0.00	0.00	0.00
	Asparagus densiflorus	2.47	0.00	0.00	0.00	8.71	5.77
	Saussurea neo-serrata	2.47	0.00	0.00	0.00	0.00	0.00
	Athyrium multidentatum	0.00	9.12	25.28	39.20	40.55	35.77
	Artemisia gmelinii	0.00	8.06	0.00	0.00	0.00	0.00
	Equisetum sylvaticum	0.00	6.13	12.72	0.00	15.61	20.58
	Atractylodes japonica	0.00	6.00	0.00	0.00	0.00	0.00
	Vicia unijuga	0.00	5.96	0.00	0.00	9.32	0.00
	Vicia pseudorobus	0.00	5.96	0.00	0.00	9.32	0.00
	Carex callitrichos	0.00	0.00	28.09	14.55	0.00	0.00
	Artemisia selengensis	0.00	0.00	16.08	0.00	0.00	0.00
	Carex lanceolata	0.00	0.00	7.09	0.00	0.00	0.00
	Veronica sibirica	0.00	0.00	4.01	0.00	0.00	0.00
	Pyrola incarnata	0.00	0.00	0.00	14.39	20.39	28.53
	Artemisia sieversiana	0.00	0.00	0.00	9.20	0.00	0.00
	Angelica amurensis	0.00	0.00	0.00	6.83	0.00	0.00
	Equisetum pratense	0.00	0.00	0.00	0.00	15.89	0.00
B	*Corylus heterophylla*	110.01	93.98	79.62	107.80	84.75	116.80
	Lespedeza bicolor	96.49	81.79	98.86	91.40	68.38	63.72
	Rhododendron dauricum	32.74	61.94	39.62	0.00	0.00	0.00
	Sorbaria sorbifolia	23.63	6.11	0.00	0.00	0.00	0.00
	Lonicera edulis	20.25	24.52	36.92	62.02	0.00	0.00
	Spiraea salicifolia	16.88	15.69	0.00	0.00	0.00	0.00
	Spiraea chamaedryfolia	0.00	15.97	45.00	20.93	0.00	0.00
	Rosa acicularis	0.00	0.00	0.00	17.85	68.75	0.00
	Rosa davurica	0.00	0.00	0.00	0.00	2.72	36.03
	Vaccinium uliginosum	0.00	0.00	0.00	0.00	21.88	83.45
C	*Betula platyphylla*	119.54	157.57	119.37	108.60	124.14	90.79
	Salix matsudana	70.18	22.55	61.08	45.30	36.50	23.03
	Populus davidiana	66.04	55.16	47.89	69.87	29.04	17.67
	Betula davurica	44.23	42.86	38.89	21.88	13.54	7.05
	Quercus mongolica	0.00	21.85	32.76	27.18	38.18	74.53
	Larix gmelinii	0.00	0.00	0.00	27.18	68.60	60.34
	Tilia amurensis	0.00	0.00	0.00	0.00	0.00	26.60
D	*Betula platyphylla*	191.94	167.18	171.52	189.39	203.82	90.49
	Betula davurica	58.52	80.20	61.72	38.07	40.70	25.51
	Salix matsudana	49.54	21.60	11.71	3.39	1.71	0.00
	Populus davidiana	0.00	18.34	1.08	16.82	4.85	22.72
	Quercus mongolica	0.00	12.68	26.44	19.61	4.79	18.32
	Larix gmelinii	0.00	0.00	27.53	32.72	44.13	142.95

Notes: A---herb layer, B---shrub layer, C---Sapling layer, D---Tree layer; S_1: 1 year after fire, S_4: 4 years after fire, S_9: 9 years after fire, S_{15}: 15 years after fire, S_{20}:20 years after fire, S_{80}: 80 years after fire

Table 2. Important value of species in different stages after forest fire in forest type B (upper slope)

Layer	Species	Important value (%)					
		S_1	S_4	S_7	S_{13}	S_{20}	S_{80}
A	*Canex ussuiensis*	72.93	46.18	63.93	114.07	163.53	183.07
	Hemerocallis minor	46.63	8.81	34.45	33.95	0.00	21.15
	Deyeuxia angustifolia	45.82	123.61	88.72	74.74	35.35	0.00
	Equisetum sylvaticum	32.26	26.22	0.00	0.00	0.00	0.00
	Vicia cracca	22.52	12.61	0.00	17.92	0.00	0.00
	Arctium lappa	13.46	0.00	12.19	0.00	0.00	0.00
	Chamaenerion angustifolium	13.46	0.00	12.03	13.36	0.00	0.00
	Filipendula palmata	13.46	0.00	0.00	14.07	0.00	14.68
	Fragaria orientalis	12.97	0.00	0.00	0.00	0.00	8.43
	Atractylodes japonica	10.97	4.40	0.00	0.00	0.00	0.00
	Geranium sibiricum	10.00	0.00	0.00	0.00	0.00	0.00
	Asparagus densiflorus	5.52	8.81	36.60	0.00	50.29	57.54
	Canex schmidtii	0.00	41.64	45.91	0.00	0.00	0.00
	Carex callitrichos	0.00	18.91	0.00	31.89	19.97	0.00
	Artemisia gmelinii	*0.00*	8.81	0.00	0.00	0.00	0.00
	Artemisia lavandulaefolia	0.00	0.00	6.17	0.00	0.00	0.00
	Athyrium multidentatum	0.00	0.00	0.00	0.00	30.86	15.12
B	*Lespedeza bicolor*	104.10	136.44	152.44	256.67	168.02	199.62
	Corylus heterophylla	84.24	127.01	82.08	0.00	89.02	100.38
	Rosa davurica	73.38	17.70	0.00	20.83	0.00	0.00
	Rhododendron dauricum	42.28	0.00	49.01	0.00	42.95	0.00
	Sorbaria sorbifolia	0.00	18.85	16.47	0.00	0.00	0.00
	Spiraea chamaedryfolia	0.00	0.00	0.00	22.50	0.00	0.00
C	*Betula davurica*	152.17	35.25	49.17	37.63	81.47	55.03
	Quercus mongolica	147.83	135.71	136.99	145.07	156.38	172.49
	Populus davidiana	0.00	129.03	113.84	97.74	62.15	19.05
	Betula platyphylla	0.00	0.00	0.00	19.56	0.00	53.44
D	*Betula davurica*	170.53	171.01	107.43	133.82	90.48	75.76
	Quercus mongolica	129.47	121.62	192.57	129.40	193.29	206.66
	Populus davidiana	0.00	7.37	0.00	11.45	16.23	5.23
	Betula platyphylla	0.00	0.00	0.00	25.34	0.00	12.35

Note: A---herb layer, B---shrub layer, C---Sapling layer, D---Tree layer; S_1: 1 years after fire, S_4: 4 years after fire, S_7: 7 years after fire, S_{13}: 13 years after fire, S_{20}:20 years after fire, S_{80}: 80 years after fire.

Similarity Index

The intercommunity of plant species in different developmental stages of natural secondary forest can reflect the subrogation of plant species composition, and it is an important index for explaining the community stability. Similarity coefficient of each vegetation layer in different growing stages after fire was calculated for forest type A and forest type B (Table 3). For Forest type A, the similarity of herb, shrub, and arborous layers and all vegetation within the forest type A between two growing stages increased gradually with increase of post-fire years. Comparably, the similarity of all vegetation is lowest (0.917) in the stage of 1-4 years after fire, indicating that in the initial stage community structure and composition has a fierce change. Then, the similarity of community between adjacent growing stages grows (Table 3), indicating that with increase of post-fire years, species replacement rate slows down and the community gradually becomes stable.

Compared with forest type A, the change low of similarity in forest type B is not evident. The similarity of all vegetation is 0.828, 0.841, and 0.913 in growing stages of 7−13 years, 13−20 years, and 20−80 years, respectively (Table 3), indicating that the vegetation distributed in steep slope has a big variation in community structure and in composition after heavy burning and needs longtime to restore. In general, after seven years of fire, the species replacement rate slows down and the community gradually becomes stable.

Table 3. Similarity index between different growing stages after fire

Layer	Forest type A				
	S_1−S_4	S_4−S_9	S_9−S_{15}	S_{15}−S_{20}	S_{20}−S_{80}
herb layer	0.948	0.954	1.000	1.000	0.997
shrub layer	0.964	1.000	0.955	1.000	0.956
Sapling layer	0.973	0.964	0.904	0.821	0.885
Tree layer	0.784	0.813	0.876	0.793	0.933
total	0.917	0.933	0.934	0.904	0.943
	Forest type B				
herb layer	0.988	0.988	0.939	0.958	0.979
shrub layer	0.785	1.000	0.967	0.967	0.911
Sapling layer	0.898	0.889	0.682	0.708	0.928
Tree layer	0.779	0.831	0.725	0.733	0.834
total	0.862	0.927	0.828	0.841	0.913

Note: S_1−S_4, S_4−S_9, S_9−S_{15}, S_{15}−S_{20}, and S_{20}−S_{80} mean 1−4, 4−9, 9−15, 15−20, and 20−80 years after fire, respectively.

Dynamic succession process of natural secondary forest after heavy fire interference

By comparing the important values (Table 1 and Table 2) of herb, shrub, sapling tree, and arbor layer species after heavy burning and analyzing the structural changes of vegetation community, we concluded the dynamic process of post-fire vegetation succession of forest type A and forest type B as shown in Fig. 4.

Conclusion

In forest type A, with post-fire timelapse, the species richness of herb, shrub and all species show a decrease tendency, while the species richness of the arbor tree presents an increase trend; whereas richness of all species mainly varies with richness changes of herb and shrub species, and becomes stable gradually. Coverage of herb, shrub, and sapling layer decreases along with year elapse after fire, while that of tree layer presents an increase trend and finally reaches a relatively stable level. No obvious law was found between total coverage of species and year span after fire. The similarity of herb, shrub, and arborous layers and all vegetation within the forest type A between two growing stages increased gradually with increase of post-fire years. Through comparison of important values and community structure changes of herb, shrub, sapling, arbor layer species of forest type A after severe fire interference, we concluded that post-fire 80 years' succession trend of forest type A is *B. platyphylla* and *L.*

gmelinii mixed forest. Its shrub layer is mainly composed of *Corylus heterophylla* and *Vaccinium uliginosum*, and the herb layer is composed of mainly *Carex tristachya*, *Athyrium multidentatum*, and *Pyrola incarnata*.

The change tendency of species richness and coverage of forest type B is similar to that of forest type A, but the number of species and coverage of each layer are evidently lower than that of forest type A. After fire, degenerated grass slope and shrub-grass slope appear on sunny slope of the ridge. After severe fire interference, the post-fire 80 years' succession trend of forest type B is *Quercus mongolica* and *Betula davurica* mixed forest. Its shrub layer is mainly composed of *lespedeza bicolar* and *corylus heterophylla,* and the herb layer is dominated by *Carex tristachya, Asparagus densiflorus,* and *Hemerocallis minor*.

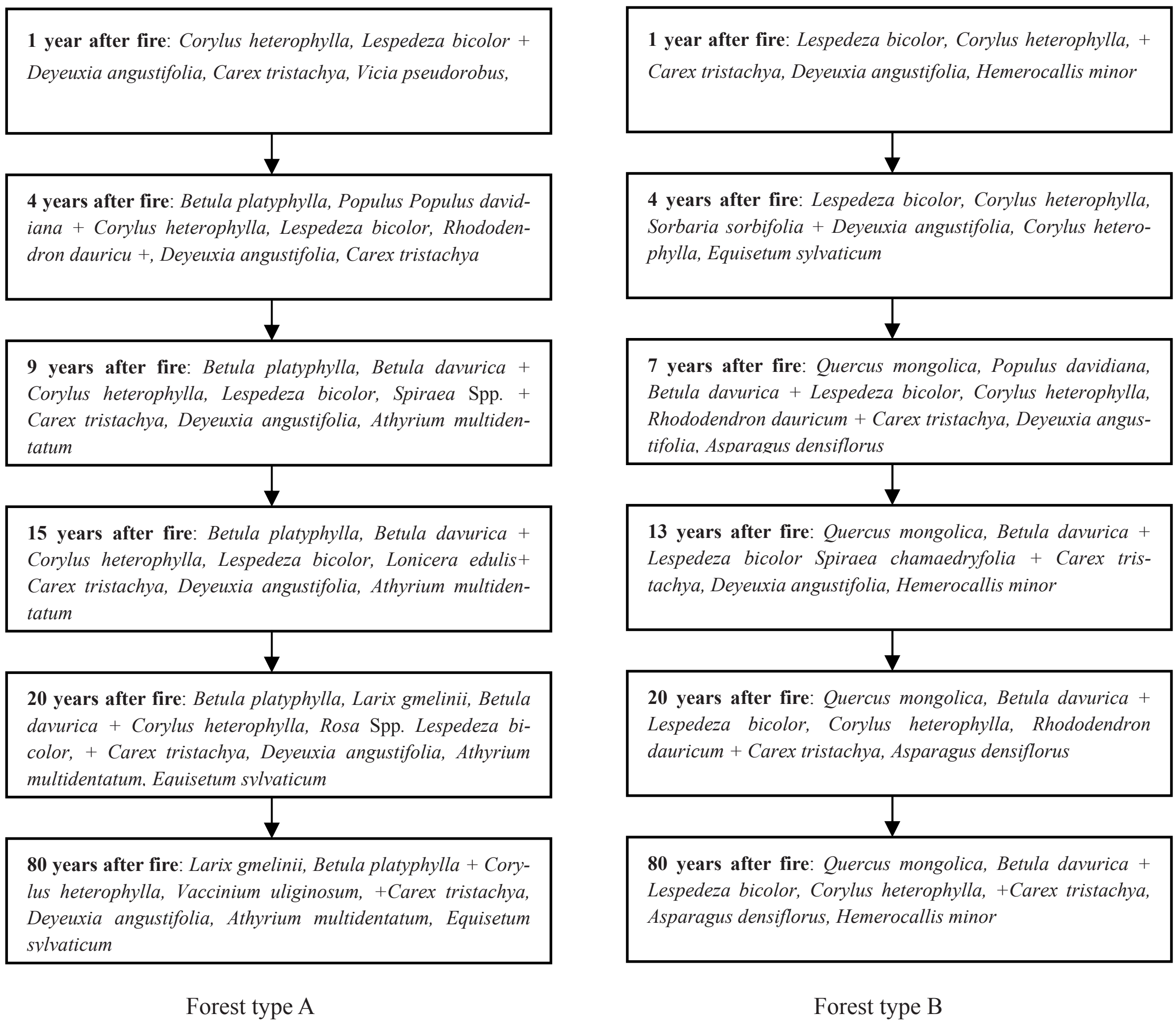


Fig. 4 The dynamic process of post-fire vegetation succession of forest type A and forest type B

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